TEMPERATURE AS A FACTOR IN THE ACTIVITY AND DEVELOPMENT OF THE CHINESE STRAIN OF TIPHIA POPILLIAVORA (ROHW.) IN NEW JERSEY AND PENNSYLVANIA[1]

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Introduction

Success in the introduction of an insect parasite from one country to another for the purpose of biological control is dependent to a great extent on the interrelation of parasite and host, that is, the acceptance of the host by the parasite for oviposition and the ability of the parasite larvæ to develop and eventually produce normal adults. It is also dependent on the introduced parasite's adaptability to the new environment, and its ability to increase and disperse rapidly.

Tiphia popilliavora is at present recorded from Japan, Chosen (Korea), and China. Individuals from these three localities are taxonomically alike and have been grouped into one species, but owing to their biological differences it has been more practical to consider them as three separate strains.

The Japanese strain has been introduced, and is at present considered one of the promising parasites of the Japanese beetle (*Popillia japonica* Newman). During 1927 and 1928, 2,192 females of the Chinese strain were liberated in southern New Jersey and eastern Pennsylvania but as yet no recoveries have been made. The present paper reports a study of the Chinese strain made at Moorestown, New Jersey, during the fall of 1928 and 1929.

Mating

It was found that the females of this species would readily mate when closely confined. The container employed in mating

[1] Contribution No. 73. Japanese Beetle Laboratory, United States Department of Agriculture, Bureau of Entomology, Moorestown, New Jersey. The photographs are by R. L. Coffin, Bureau of Entomology, Moorestown, N. J.

females for liberation is a wooden box 7 inches by 11 inches by $5\frac{1}{2}$ inches deep, the top of the box covered by a piece of plate glass sliding tightly in grooves. The box is provided with water, food, and soil. The water is put into 4-ounce bottles which are stoppered with cotton plugs covered with cheese cloth, and is fed to the stopper by means of a cotton lamp wick. The food is made of a mixture of honey and pulverized sugar, enough sugar being added to make a stiff dry candy. The food is packed into $\frac{1}{2}$-ounce metal containers which are held upright in wooden blocks; four such containers are in each box, furnishing 2 ounces of food. One inch of moist sifted soil is placed in the bottom of the box. (Plate XXXXI, Fig. 1.)

The males are confined in the boxes until their death, but the females are removed after 48 hours and replaced by newly emerged individuals. One hundred males and fifty females are confined in each box.

Mating at Various Temperatures. In making observations of mating activities, three mating boxes were equipped with thermometers. One box was retained indoors; another was placed in a screen-covered insectary subject to outdoor temperatures and indirect light, and the third was placed out of doors exposed to direct light. Each box contained 50 females and 100 males.

The box indoors remained, with a slight variation, at about 70° F., and instances of copulation could be noted throughout the day. The activity of the Tiphia could be stopped at this temperature by darkening the box, but as soon as the insects were exposed to light they again became active. On one occasion the box was heated to 85° F., and at this temperature the activity increased so greatly that the main interest was to escape from confinement.

The boxes out of doors were observed from 8 a.m. to 3 p.m., during which time the air temperature within gradually rose from 55° to 75° F. As the temperature approached 66° the males emerged from the soil but they did not attempt flight until the air had warmed to from 65° to 70°. At 70° two females emerged, and by the time 75° was reached practically all the females had emerged and were in copula. There was apparently no difference in activity between those in the box in the indirect

light of the outdoor insectary and those in the box receiving the direct light.

OVIPOSITION

The mated females used in obtaining oviposition were chosen at random, while sorting the adults for liberation, and are representative of material used for colonization.

A 6-ounce tin, fitted with a shallow telescoping lid, was used to hold the soil and Popillia grubs to obtain the ovipositions. A metal partition divides the can into four compartments to prevent the grubs from injuring one another. The soil is firmly packed about the grubs to enable them to form cells, as it is almost impossible for Tiphia to attack and successfully oviposit on grubs in loose soil. Food for the parasites consisted of drops of a solution of 1 part of honey in 9 parts of water on small squares of paraffined paper which are placed upon the soil within the tins. (Plate XXXXI, Fig. 2.)

New host larvæ were dug and brought in from the field every other day, because grubs when stored in any great numbers during the fall are very susceptible to fungous and bacterial diseases.

Oviposition at a Constant Temperature. The oviposition record of 17 females is given in Table 1. This group was kept in the soil at a constant temperature of 68° F.

Oviposition at Variable Temperatures. A group of 35 females kept at a soil temperature of 70° F. for 24 hours deposited an average of 2.4 eggs each. When the temperature was lowered to 51.5° for 24 hours the average number of eggs deposited per female was 1.6, but the average at this temperature for an additional 24 hours was 0.6. When the temperature was returned to 70° the average oviposition for 24 hours was 2.6 per female.

A second group of ten females was divided into two lots which were kept at soil temperatures ranging from 50° to 75° F. The temperatures were obtained from thermometers inserted in a can of soil and kept under the same conditions as the cans containing the host and parasite. This experiment was run for 14 days after the first recovery of field-emerging Tiphia. From Table 2 it may be seen that between 50° and 60° F. there is almost no activity. The mean soil temperature from October 7 to 21, 1928, inclusive, was taken at a depth of 3 inches, as at this depth the

TABLE 1.—Number of days of life of Tiphia wasp and record of eggs laid at a soil temperature of 68° F., during October, 1928, at Moorestown, N. J.

	Number of eggs laid on specified number of days after emergence																							
Tiphia No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0	3	2	1	2	2	2	1	0	3	3	0	4	4	2	4	2	2	2	3	4	3	2	3
2	2	1	1	1	3	2	2	0	1	1	1	2	2	2	4	3	2	2	4	4	2	3		
3	2	1	2	2	4																			
4	0	1	2	1	4	2	1	1	4	2	0	3	3	2	4	2	3	4	2	2	3	1		
5	1	2	2	1	3	4	1	1	2	2	0	3	4	3	3	3	1	2	3	3	3	2	2	1
6	3	0	1	1	3	3	1	1	2	2	0	3	4	3	2									
7	0	1	3	2	1	0	1	1	1	3	1	2	3	2	1	3	2							
8	0	3	1	2	0	2	1	0	4	4	0	0												
9	2	1	1	0	0	1	2	1	1	1														
10	1	1	1	0	1	1	4	0	4	1	3	4	2	2	4	1	2	4	3	1	3	1	2	2
11	0	3	2	3	1	2	1	1	4	4	3	3	3	1	2	1								
12	0	1	2	1	0	2	2	1	4	2	2	3	1	2	4	3	2	4	3	3	3	1	3	1
13	2	2	2	1	0	3	2	1	0	4	4	4	3	3	4	4	2	3	3	3	3	4	1	
14	0	2	1	0	0	2	2	0	3	4	3	4	2	1	3	3	1	2	3	2	2			
15	1	2	3	0	0																			
16	0	2	1	2	0	3	3	2	3	4	4	3	2	3	4	4	4	3	3	4	2	3	3	4
17	1	1	1	2	0	0	1	0	2	3	2	2	2	2	2	2	2	3	2	3	2	2	1	1

Maximum number of eggs from one female 100
Maximum number of days lived 45
Minimum number of eggs from one female 6
Minimum number of days lived 5

TABLE 1.—*Continued*

Tiphia No.	Number of eggs laid on specified number of days after emergence																					Total	
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	Days	Eggs
1	3	1	2	2	2	2																30	66
2																						23	48
3																						5	11
4																						22	47
5	2	3	1	1	2	2	2	3	2	1	3	1	1									37	76
6																						15	29
7																						17	27
8																						12	17
9																						10	10
10	2	2	1	2	2	2	1	2	2	2	2											35	68
11																						16	34
12	1	3	1	3	2	2	2	1														32	65
13																						23	58
14																						21	40
15																						5	6
16	1	2	4	2	3	3	3	2	1	2	3	0	2	1	1	2	1	1	0	0	0	45	100
17	1	2	2	1	4	1	2	2	1	2	1	2										39	63
																						387	765

Total eggs obtained 765
Average number of eggs from one female 45
Daily average eggs per female 1.98
Average length of life ..... 22.77 days

TABLE 2.—*The Effect of Temperature on Oviposition Under Controlled Conditions with a Comparison of Existing Soil Temperatures in the Field, at Moorestown, N. J.*

1929	Mean soil temperature in the field	1st Lot		2nd Lot	
		Mean soil temperature in the tins	Average ovipositions per female	Mean soil temperature in the tins	Average ovipositions per female
	°F.	°F.		°F.	
Oct. 8	60.0	75.0	1.4	56.0	0.0
Oct. 9	57.5	75.0	1.8	62.5	0.0
Oct. 10	56.0	69.0	0.6	50.5	0.0
Oct. 11	55.0	50.0	0.0	70.0	0.2
Oct. 12	54.0	50.0	0.0	70.0	0.2
Oct. 13	56.0	50.0	0.0	68.0	0.0
Oct. 14	59.0	72.5	1.2	71.0	0.2
Oct. 15	58.2	72.5	1.6	72.5	0.7
Oct. 16	57.5	72.5	2.0	72.5	1.7
Oct. 17	57.5	55.0	0.0	72.5	1.0
Oct. 18	54.2	55.0	0.2	73.5	0.7
Oct. 19	50.7	72.5	2.2	73.5	1.5
Oct. 20	51.0	72.5	1.0	72.0	1.7
Oct. 21	52.5	72.5	1.2	73.0	2.0

greatest number of grubs will be found at this time. The mean soil temperature at this depth for the month of October was 55.2° F.

Unmated Females. Five unmated females were placed with grubs in soil immediately after emergence. As a check, five mated females were kept under the same conditions and at the same time with the unmated lot. The unmated females oviposited 110 times and the mated females 100 times. The soil was kept at a room temperature of approximately 70° F.

Rearing of Parasitic Larvæ

The grubs bearing parasite eggs were packed in soil in cross-section trays. Each compartment permits the grub to be surrounded by 2 cubic inches of soil. The tray has 196 sections in all, but only 144 are used for rearing purposes; the outer rows of compartments are subject to rapid drying and are filled with soil only. A few grains of wheat are placed in each section as

food for the host, for unless this is done the grub will move out quite frequently, sometimes completely leaving the tray. (Plate XXXXI, Figs. 3 and 4.)

Rearing at Room Temperatures. Fifty-two per cent of the Tiphia grubs issuing from parasitized Popillia grubs reared in soil at a room temperature of about 70° F. formed cocoons.

Rearing at Open Insectary Temperatures. Seven hundred and sixty parasitized grubs were reared in an outdoor insectary, at temperatures given in Table 3, which shows the maximum, minimum, and average for five-day intervals from September 11 to October 30, 1929, inclusive.

TABLE 3.—*Air Temperatures for the Period from September 11 to October 30, 1920, at Moorestown, N. J.*

1928	Maximum	Minimum	Mean
	°F.	°F.	°F.
Sept. 11–15	83.7	64.6	74.1
Sept. 16–20	74.1	60.0	67.0
Sept. 21–25	72.7	50.5	61.6
Sept. 26–30	59.6	44.5	52.0
Oct. 1–5	67.8	46.2	57.0
Oct. 6–10	60.3	51.0	55.6
Oct. 11–15	77.7	50.0	63.8
Oct. 16–20	78.4	59.4	68.9
Oct. 21–25	70.8	46.5	58.6
Oct. 26–30	55.7	35.4	45.5

When reared at these temperatures 4.3 per cent of the resulting Tiphia grubs formed cocoons. Only two cocoons were formed from ovipositions obtained after the first 10 days.

Rearing Under Natural Conditions. Beetle larvæ bearing 1,900 parasite eggs were "planted" in a sodded plot out of doors. The ovipositions had been obtained from September 16 to October 30, 1928. The grubs were placed individually in holes 1 inch in diameter, at a depth of 2 inches beneath the surface. The holes were packed firmly with soil and the plug of sod replaced.

The plot was completely dug over from October 25 to November 12, in 1929, and a total of 14 cocoons were recovered, all of

which were found 14 inches or more below the surface. No cocoons were developed from ovipositions placed in the field after October 2. The mean soil temperatures in October during the period of development of the parasite egg and larva were 58.6° F. at 3 inches, 59.8° at 6 inches, and 59.7° at 9 inches.

Rearing the Eggs of Unmated Females. The parasitic larvæ resulting from ovipositions by unmated females were reared at room temperatures, and the parasitic larvæ from the mated females were used as a check and reared under the same conditions and at the same time.

The progeny from the unmated females developed and formed 51 cocoons from 93 eggs, or 54.8 per cent. Only 42 per cent of the parasites from fertilized eggs formed cocoons.

TIME OF EMERGENCE

Adults from the imported cocoons of this strain were more erratic in the time of emergence than any of the imported species reared under the same conditions. The peak of the emergence occurred the second year of storage and extended over a period of three months.

The field plot in which the parasitized grubs were "planted" in 1928 was observed the following season in order to check on the time of emergence under natural conditions. In September two cocoons were dug up which contained well formed pupæ. On October 7 a male was found burrowing from the soil. During the next three days two more males were taken while they were hovering over the grass. This time of the year is practically the same as recorded for emergence in China. An examination of the cocoons dug from the plot showed that nine adults had emerged, two cocoons contained dead adults, and one cocoon a live larva in apparently good condition. Two cocoons were perforated with numerous small holes which gave the appearance of having been made by mites. There was no evidence of what the cocoons might have contained, nor was there any evidence of adult emergence.

Though only a few cocoons were recovered, the indications are that the emergence occurs early in October and that there is a predominating tendency to a one-year cycle, whereas insec-

tary-reared material was more indicative of a two-year cycle with emergence in September, October, and November.

SUMMARY

The optimum temperatures for mating of the Chinese strain of *Tiphia popilliavora* (Rohw.) were observed to be between 65° and 75° F. The average length of life for adults was 22.77 days when kept at a constant temperature of 68° F. With the emergence occurring the second week in October, only 10 of the 22 days of life would be at all favorable for mating.

The soil temperatures in October do not inhibit oviposition, but will hold this activity at a minimum. The average mean soil temperature at 3 inches during October from 1924 to 1929 was 55.2° F.

Temperatures below 60° F. are very unfavorable for the development of the parasitic larvæ and for cocoon formation. The mean soil temperatures during the developmental period are 59.8° F. at 6 inches and 59.7° F. at 9 inches.

CONCLUSION

The records obtained of the fecundity, the development of the parasitic larva on the host, and the percentage of adult emergence would indicate that the Chinese strain of *Tiphia popilliavora* may become a factor in the control of the Japanese beetle in infestations occurring south of New Jersey and Pennsylvania, but in the present latitude of heavy beetle infestation the existing climatic conditions at and after the time of emergence are not favorable for adult activity, or for the development of eggs and parasitic larvæ.

PLATE XXXXI

Figure 1. Mating box with equipment removed.
Figure 2. Six-ounce tins used for obtaining ovipositions.
Figure 3. Cross-section tray used for rearing.
Figure 4. Cross-sections removed and inverted showing the formed cocoons.